# Glacial Radiocarbon Age-Conversion: A Response

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*ANTIQUITY recently published the first continuous Glacial radiocarbon calibration curve (van Andel 1998), which is based on the geomagnetic extrapolations of Laj et al. (1996), but was already challenged by Van der Plicht (1999) in the immediately succeeding volume of ANTIQUITY. Van der Plicht´s reply urges caution and suggests to prehistorians the unreliability of radiocarbon calibration for the Last Glacial period "for the purposes of prehistoric and environmental calibration" (Van der Plicht 1999, 119) until a number of issues concerning the time-scales of the Greenland GRIP and GISP2 ice-cores and the Japanese Lake Suigetsu varve chronology published by Kitagawa & Van der Plicht (1998a; 1998b) shall have been solved. This response to Van der Plicht (1999) documents that the data sets required for such purposes are already available today and - with possibilities to test each subset of data - do, indeed, allow first approximations of Calendric Age-Conversions of Last Glacial radiocarbon data.*

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Research on radiocarbon age calibration has a rather complicated history. Over the past 30 years there have been innumerable extensions, revisions, and corrections of the underlying Holocene tree-ring chronologies, and equally numerous improvements in equipment and techniques necessary for the highly accurate and reproducible $^{14}C$ measurements required in archaeology. It is worth noting that research into radiocarbon calibration has historically received major inputs from archaeological reasoning. In brief, the history of Holocene radiocarbon calibration is a history of revisions, and the recently published and recommended data set INTCAL98 (Stuiver & Van der Plicht 1998) presently represents the most advanced of these.

Today archaeological chronologies are largely based on radiocarbon data. This applies to the late Middle Palaeolithic as well as to the entire Upper Palaeolithic and all younger periods. For archaeological purposes, an approximation of calendric time-spans is necessary for the basic understanding of questions referring to population dynamics, demography, and material cultural development and change. Thus, from an archaeological, *quasi* 'historical' perspective, there is nothing unusual about van Andel´s (1998) proposal to construct a first continuous Last Glacial radiocarbon calibration curve. Van Andel´s paper was already out-of-date by the time it appeared in print, but not therefore necessarily wrong, neither do the newly published Suigetsu data (Kitagawa & Van der Plicht 1998a; 1998b; Van der Plicht 1999) invalidate van Andel´s approach. In our view, Last Glacial radiocarbon calibration is mainly a question of synchronization and integration of the different time-scales underlying data sets which are already available, and which may be of use for the purposes of calibration (Bond *et al.* 1993; Jöris & Weninger 1998; 1999a; Kitagawa & Van der Plicht 1998a; 1998b; Voelker *et al.* 1998).

The general need of calibrated $^{14}C$ data in archaeological approaches becomes obvious when prehistorians are forced to switch from the calendric to the radiocarbon scale in the Younger Dryas simply because that is where the end of the tree-ring chronologies is presently reached, or when it is necessary to evaluate how many hominid generations may have been involved when working with models such as continuity or replacement between Neandertals and anatomically modern humans (Jöris & Weninger 1999a).

Alongside questions concerning calendric (absolute) time, the relationship of changes in past $^{14}C$ levels to palaeoclimate signatures presents the greatest challenge for the archaeologist. Attempts to reliably synchronize deep-sea records with the high-resolution Greenland ice-core time-scales (Bond *et al.* 1993; Jöris & Weninger 1998; Voelker *et al.* 1998) have not merely made it possible to construct an extended Last Glacial calibration curve for the last 50.0 ka, but also adequately link $^{14}C$ levels to climate change. $^{14}C$ data derived from the marine cores and transferred to the GRIP and GISP2 ice-core time-scales reveal alternative calibration graphs. Disregarding the absolute age-dimension, links between $^{14}C$ levels and palaeoclimate signatures can be established, allowing transferral of these proxies even to terrestrial records.

Referring to the calendric dimension, whereas a GISP2-based calibration curve is in good agreement with the available U/Th-$^{14}C$-coral data for the time period preceeding the Late Glacial, the GRIP ages seem to be too young (Jöris & Weninger 1998; 1999a-b). Arguments that make the GISP2 chronology in its long-term trend more reliable than the GRIP-chronology are that the counting of annual ice layers is established further back in time for GISP2 ages than for GRIP, and that the oldest part of GISP2 is synchronized with the Antarctic Vostok chronology (Meese *et al.* 1994; Sowers *et al.* 1993), which is itself calibrated with the orbitally tuned, stacked deep-sea SPECMAP chronological framework (Martinson *et al.* 1987; Sowers *et al.* 1993). An important marker to control the validity of the combined U/Th-GISP2-Vostok-SPECMAP time-scale is the Toba eruption some 72 ka ago, which happened at the very end of IS 20 (IS = interstadial; *cf.*: Johnsen *et al.* 1992).

Among other deep-sea records, the North Atlantic core PS2644 (Voelker *et al.* 1998) shows the highest resolution of the $^{14}$C scale in relation to sample depth, and appropriate linkages to the GISP2 ice-core ages have been established by Voelker *et al.* (1998). While all $^{14}$C data derived from the marine records require corrections for specific reservoir values, $^{14}$C data from terrestrial sequences do not. Furthermore, comparing $^{14}$C data of benthic and planktonic foraminifera Voelker *et al.* (1998) find indications for possibile changes in North Atlantic palaeo-revervoir values.

AMS-dates of terrestrial macrofossils from the Japanese Lake Suigetsu varves (Kitagawa and Van der Plicht 1998a; 1998b; Van der Plicht 1999) are not affected by $^{14}$C reservoir problems, but other difficulties such as e.g. sample taphonomy (terrestrial macrofossils in varved sediments generally have to be judged as reworked) and discontinuities in the varved record may play major roles.

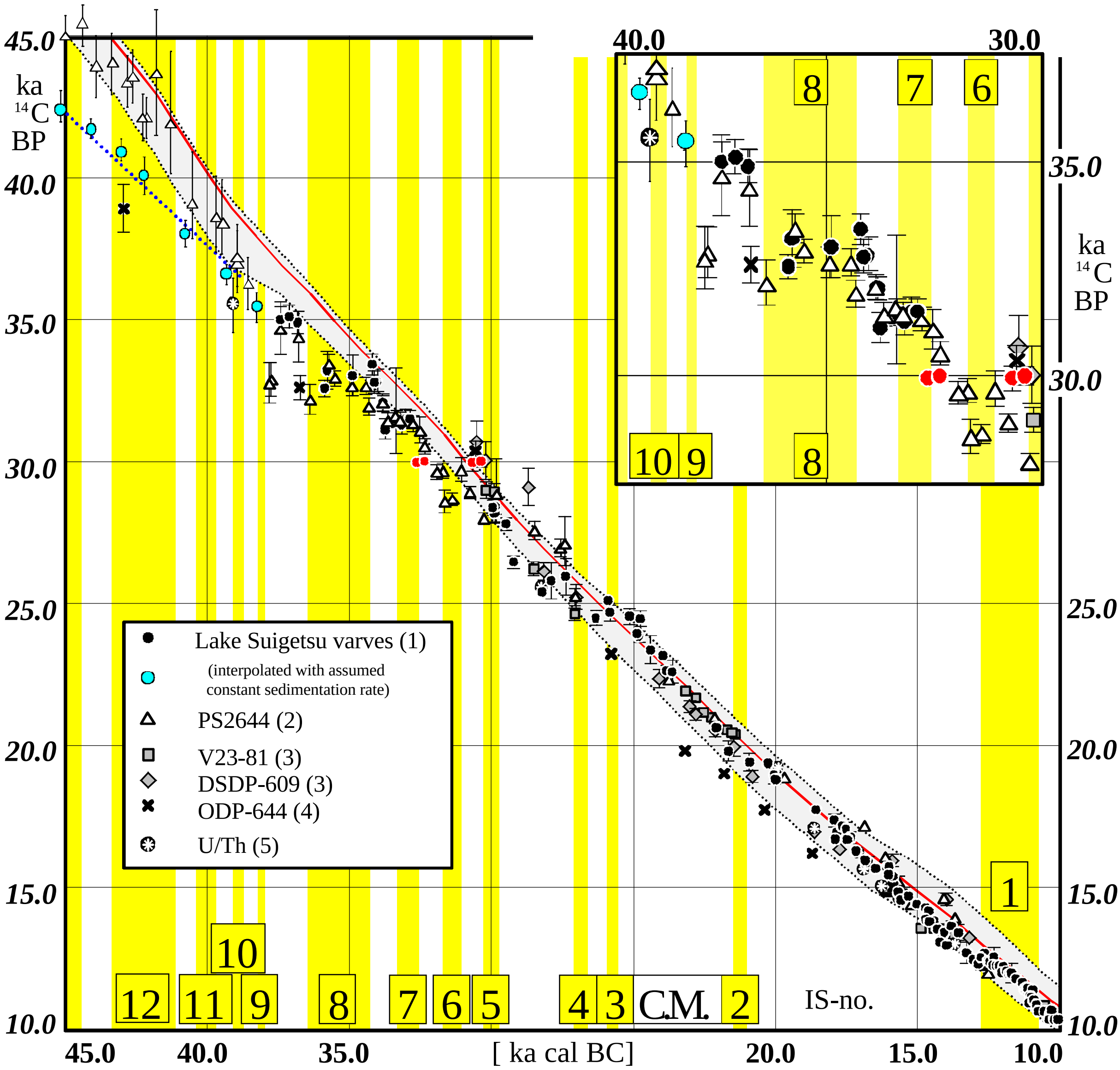


**fig. 1: Time-window 10.0 - 45.0 ka cal BC, showing paired $^{14}$C and calendric ages for different data sets. Sequence of interstadials (IS-no.: yellow underlay) following Johnsen *et al.* 1992, tranferred to GISP2 time-scale (*cf*. Meese *et al.* 1994; Sowers *et al.* 1993). C.M. = Cold Maximum. Grey shaded band shows geomagnetic calibration curve (Lay e*t al.* 1996) as used in Van Andel´s (1998) approach (with mean values shown as red solid line; note asymmetric error). Data points (showing ± 1 s error bars for errors > ± 200 BP) derive from: Lake Suigetsu varves, marine sediments (North Atlantic cores PS2644, V23-81, DSDP-609, ODP-644; all $^{14}$C-ages on planktonic foraminifera), and corals (U/Th-$^{14}$C-data). Inlay: enlargement of the time-window 30.0 - 40.0 ka cal BC, showing the overall agreement between PS2644 and Suigetsu data, with the later (basel part) shifted 1,930 cal yrs to older ages, with split Suigetsu data shown twice (red), and with depth-age interpolated Suigetsu data (blue); blue dotted line represents linear extrapolation through the combined data set of the last 40 ka. (1) Kitagawa & Van der Plicht 1998a; 1998b; (2) Voelker *et al.* 1998; (3) Bond *et al.* 1993; (4) Fronval *et al.* 1995; (5) Bard *et al.* 1993; 1998. Time-scales for (3)+(4) following Jöris & Weninger 1998.**

In the origional Suigetsu publication, Kitagawa and Van der Plicht (1998a) estimate the total error in the varve sequence at around 1.5%, which in total amounts to some 437 cal yrs for the almost 30 ka long $^{14}$C dated part of the sequence. Without further elaboration Kitagawa and Van der Plicht (1998a; *cf*. Van der Plicht 1999) offer an alternative $\Delta^{14}$C-record for Suigetsu which assumes a linear error amounting to the total of 2,000 cal yrs at the start of the $^{14}C$-dated sequence and the authors therefore "consider all data beyond 20,000 cal BP as minimum ages" (Van der Plicht 1999). In both of the models (437 and 2,000 cal yrs) evaluating errors in the varve sequence abrupt sedimentational discontinuities are excluded, and $\Delta^{14}C$-records reach extreme values some 31 to 32 ka ago (Kitagawa & Van der Plicht 1998a; Van der Plicht 1999), which - following Van der Plicht – might most probably be caused by a geomagnetic excursion. Van der Plicht´s (1999) article in ANTIQUITY addresses the question of the timing of this excursion and compares the $\Delta^{14}C$- with $^{10}Be$-peaks (another cosmogenic derived isotope) obtained from various records. It must however be emphazised that the underlying time-scales of the comparitive $^{10}Be$-data sets are neither sufficiently synchronized with each others nor necessarily calendric. Furthermore, the $^{10}Be$-event - as discussed by Van der Plicht - may truly be one and the same, as indicated by its relative chronological position. Thirdly, the assumption of a major varve sedimentation gap in the Suigetsu sequence at around 30 ka cal BC would imply a completely different $\Delta^{14}C$-record.

The importance of the Lake Suigetsu data set is undisputed. Indeed, compared with other records such as PS2644 it has to be seen as a subset of the total amount of data available for Last Glacial radiocarbon age-conversion.

Changes in atmospheric $^{14}C$-production show up in the Suigetsu record with a pattern almost indentical to that recorded in the PS2644 core. Striking similarities in the patterns of $^{14}C$-level *vs*. the calendric dimension indicate a varve sedimentation gap in Lake Suigetsu at around 30 ka cal BC, and imply a downward shift of the basal Suigetsu sequence by some 1,930 cal yrs (Jöris & Weninger 1999a-b; *cf*. Van der Plicht 1999).

To summarize, in pushing calibration back to the technical limits of the radiocarbon method, the discrepancies between subsets of potential calibration data described above have been minimized by stepwise critical testing of the different data sets against each other. Data from corals (U/Th *vs*. $^{14}C$), the North Atlantic core PS2644 (and other $^{14}C$-data from deep-sea cores) and Lake Suigetsu agree well if 1,930 cal yrs are inserted into the Suigetsu record at around 30 ka cal BC, and they produce both appropriate calendric ages as well as highly reliable links to palaeoclimate signatures relative to a combined U/Th-GISP2-Vostok-SPECMAP-time-scale (Jöris & Weninger 1999a-b).

Following a proposal by Pieter Grootes the term $^{14}C$-calibration should be restricted to tree-ring calibration and we therefore refer first-order approximations of Last Glacial $^{14}C$-ages to the calendric time-scale as 'Calendric Age-Conversions'.

Ignoring Van der Plicht's (1999) warning, we would like to encourage multidisciplinary approaches as undertaken by van Andel (1998). The level of accuracy of age conversion with tree-ring calibration possible today for the Holocene by using the INTCAL98 data set will not, of course, be achieved for the Last Glacial overnight. However, seen from today´s perspective, neither was this precise level of calibration available for the Holocene during 40 years of continuous up-dating and revision of radiocarbon calibration methods, but archaeologists were nevertheless still encouraged to make use of the most recent releases by the radiocarbon community. We therefore believe that prehistorians must be allowed to incorporate the calendric variable into their archaeological considerations today, and not at some hypothetical future date.

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